DEVELOPMENT OF A GASIFIER FOR FUELING OF A DIESEL ENGINE

A Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology
in
Mechanical Engineering
by

Deepali Rath (107ME065)

Under the guidance of
Prof. S. Murugan

Department of Mechanical Engineering
National Institute of Technology
Rourkela 769008

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CERTIFICATE

This is to certify that the thesis entitled, **"Development of a gasifier for fueling of a diesel engine"** submitted by **Deepali Rath(107ME065)** in partial fulfillment of the requirements for the award of **Bachelor of Technology Degree** in **Mechanical Engineering** at National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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Last but not the least, I express my profound gratitude to the Almighty and my parents for their blessings and support without which this task could have never been accomplished.

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ABSTRACT

Diesel engines are highly preferred for transportation since they are highly efficient and durable in the long run. However, because of lack of crude oil reserves, fuel cost and emission norms, alternative fuels are of high interest to replace the diesel fuel in diesel engines. Many alternative liquid fuels for diesel engines such as bio-diesel, alcohol have been introduced in the recent past. These are obtained from biomass. Gaseous fuels are better than liquid fuels. Therefore, in this project a gasifier was designed and fabricated to get producer gas. The design of the entire gasifier along with the details of every part is provided. The method of fabricating each part is also detailed. The feedstock or raw material used for gasification in this project is chips of wood which is a biomass available in large quantity. The diesel engine was run with diesel as the main fuel and the producer gas obtained from biomass was sent along with air. The performance and combustion characteristics of the engine were studied. A reduction in the consumption of diesel fuel was observed as the brake specific energy consumption was found to decrease when both diesel and producer gas were used. Also, a marginal increase in thermal efficiency was noted with the use of producer gas along with diesel as the fuel.

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

Crude oil and petroleum products are proposed to become very costly. The fuel economy of engines is improving day-by-day and it will continue to improve in the future. On the other hand, there has been an enormous increase in the number of vehicles. This has started dictating the demand for fuel. In the near future, gasoline and diesel are expected to become more costly. Alternative fuel technology has become more popular with increased use and depletion of fossil fuels. There have been some internal combustion (IC) engines fuelled with non-gasoline or diesel oil fuels, although, their numbers have been relatively small. As the cost of petroleum products is high, many developing countries are trying to use alternate fuels for their vehicles.

Another factor that has been motivating the development of alternate fuels for the IC engine is the emission problems of gasoline and diesel engine. The large number of automobiles today is a major contributor to the air quality problem of the world. Quite a lot of improvements have been made in decreasing the emissions from the engines. But, these improvements have been nullified by the increase in the number of automobiles. Also, a large percentage of crude oil needs to be imported from other countries having large oil-fields.[1]

1.1. ENERGY SCENARIO IN INDIA

India is world's eleventh largest energy producer currently and accounts for nearly 2.4% of the world's total energy production and 3.7% of the world's total annual energy consumption which makes it the sixth largest energy consumer. The electricity production in India relies heavily on coal energy sources, hydropower and natural gas. About one-third of the total energy consumed is contributed by renewable energy technologies. Coal presently provides 69% of the electricity demand in India. India has around 10% of the world's coal reserves but this coal is of low quality and thus is an inefficient source and highly polluting. The increasing concerns for environment have driven the need to find alternatives to this energy source. To meet the ever increasing demand energy imports such as oil and natural gas have been increasing. Energy security has become an important aspect to consider. [2]We have to use the energy sources efficiently and conserve them and also develop alternate sources of energy.

1.2 RENEWABLE ENERGY TECHNOLOGIES IN INDIA

The potential of renewable energy resources has not been properly tapped in India. For deploying renewable energy products and systems, India has one of the largest programs in the world. Biomass, biogas, solar power, wind power and hydro power are the main sources of renewable energy in India. About 5% of the total power production in India is contributed by renewable energy sources. As can be observed from Table 1, none of the potentials of the various renewable resources has been reached. Renewable systems are cleaner and environment friendly alternatives compared to the traditional fuels used. [2]Thus, in the present work a gasifier was designed and developed which could gasify any form of biomass which is a renewable form of energy. In the present work waste wood chips obtained from workshop were used for gasification. The producer gas obtained from the developed gasifier was sent along with air into a diesel engine with diesel as the primary fuel and the performance and combustion characteristics of the engine were studied.

Table 1. Renewable energy sources with their estimated potential and the present number of installations or total capacities [2]

Source/System	**Estimated potential (in MW)**	**Cumulative installed capacity (in MW)**
Wind power	45,000	3595
Biomass power	16,000	302.53
Bagasse cogeneration	3500	447.00
Small hydro(up to 25 MW)	15,000	1705.63
Municipal solid waste	1700	17
Industrial waste	1000	29.5
Biomass gasifiers	-	66.35
Solar photovoltaic power plants	-	1.566
Source/System	**Estimated potential (in numbers)**	**Cumulative installed capacity (in numbers)**
Improved chulhas	120 million	35.20 million
Solar street lighting systems	-	54,795
Home lighting systems	-	342,607
Solar lanterns	-	560,295
Box type solar cookers	-	575,000
Solar photovoltaic pumps	-	6818
Wind pumps	-	1087

1.3 TYPES OF FUELS

There can be three types of fuels, viz. solid, liquid and gaseous. These days, automobiles are using only liquid fuels of petroleum origin. Gaseous fuels are best suited for internal combustion engines since their ignition delay is very small. At present, a number of biomass fuels are being evaluated like fuel oil made from wood, soya beans, rape seed etc. These fuels are easily available and have low cost. Producer gas is an alternate fuel tried in diesels. Conventionally, it is made by flowing air and steam through a thick coal or coke bed which ranges in temperature from red hot to low temperature. The oxygen in air burns the carbon to CO_2. This CO_2 gets reduced to CO by contacting with carbon above the combustion zone. The freed oxygen combines with carbon and steam gets dissociated which introduces hydrogen. Producer gas has a high percentage of nitrogen since air is used.[1]

1.4 OBJECTIVES

1. To design an updraft gasifier that could gasify chips of wood to produce producer gas. For this, a literature survey was done .The basic working principle of a gasifier was understood and a suitable design for each component was adopted. The design of the entire gasifier was developed.
2. To fabricate the entire gasifier. Each part of the gasifier was fabricated by a suitable fabrication process and the individual parts were assembled.
3. To run a diesel engine with diesel as the primary fuel and producer gas is sent along with air. For this, an experimental setup was designed connecting the gasifier and the engine inlet.
4. To study the performance and combustion characteristics of the engine for concluding on the consumption of diesel fuel and the thermal efficiency of the engine

1.5 ORGANIZATION OF THE THESIS

The entire thesis is divided into six chapters.

Second chapter consists of literature survey. Various works in the field of gasifiers are studied and presented .The various designs of gasifier are studied along with merits and demerits of each design and the ease of fabrication of a design. Relevant information is obtained which is helpful for the design and development of the gasifier.

Third chapter deals with the theory of gasification. In this chapter, the reader will know about the basic principle of gasification, the thermo chemical processes involved in the process, the various zones of a gasifier and about the types of gasifiers.

Fourth chapter deals with the design and development of the gasifier. Here, the design of each component of the gasifier is developed. The material to be used for each part is decided and the entire gasifier is fabricated accordingly.

Fifth chapter deals with experimental work. In this chapter the reader will come to know about the experimental setup and the initial running of the gasifier. The specifications of the engine and all the equipments used are specified.

Sixth chapter gives the important results and conclusions. Here, the performance characteristics and the combustion characteristics are studied are deductive conclusions are made. In this project the reader will be able to understand the project outcomes and the future scope of work that can be performed.

CHAPTER 2

LITERATURE SURVEY

2. LITERATURE SURVEY

►**AVDHESH KUMAR SHARMA** [3,12] carried out experimental study on a 75 kW downdraft biomass gasifier system to obtain temperature profile, gas composition, calorific value and trends for pressure drop across the porous gasifier bed, cooling-cleaning train and across the system as a whole in both firing as well as non-firing mode. In the reactor, both gas and biomass feedstock move downward as the reaction proceeds. While biomass flows because of gravity, air is injected with the help of a blower. The experiments were designed to obtain fluid flow characteristics of the gasifier and also to obtain the temperature profile in the reactive bed, the gas composition and calorific value. For non-firing gasifier, the extinguished bed showed greater pressure drop as compared to a freshly charged gasifier bed. The pressure drop across the porous bed was found to be sensitive with change in flow rate. When used in firing mode, the higher temperature in bed led to better conversion of non-combustibles component in the resulting gas and thus improved the calorific value of the product gas.

► **PRATIK N.SHETH, B.V.BABU**[4,11] carried out experimental studies on producer gas generation from wood waste in a downdraft biomass gasifier. They used sesame wood or rose wood as biomass. They observed that biomass consumption rate decreases with an increase in the moisture content and it increases with an increase in the air flow rate. The performance of the bio mass gasifier system was evaluated in terms of producer gas composition, the calorific value of producer gas, gas generation rate, zone temperatures and cold gas efficiency. Thermocouples were placed inside the gasifier at different locations to measure the temperature of various zones of gasifier. They found the producer gas composition using gas chromatograph.

►**PENGMEI LV, ZHENHONG YUAN, LONGLONG MA, CHUANGZHI WU, YONG CHEN, JINGXU ZHU**[5,14,15] studied the characteristics of hydrogen production from biomass gasification. They used a self-heated gasifier as the reactor and char as the catalyst. The steady temperatures of the pyrolysis zone, combustion zone and reduction zone were recorded. Equivalence ratio(ER) is defined as the actual oxygen to fuel ratio divided by the stoichiometric oxygen to fuel ratio needed for complete combustion. The temperature of the neck was found to increase with feeding rate for similar ER values. For increasing the production capacity, accelerating the feed rate is essential but excessively high feeding rate will result in a higher gas yield and a shorter gas residence, thus degrading gas quality. The temperature increases with feeding rate but hydrogen yield decreases with feeding rate.

►**MD. ALI AZAM, MD. AHSANULLAH, SULTANA R. SYEDA**[6] constructed a downdraft gasifier at laboratory scale and checked whether the required composition of producer gas could be attained or not. The construction of the gasifier is based on the design proposed by Bhattacharya et al**.** [7]The various parts of the gasifier like reaction chamber, fuel hopper, gas outlet and air inlet were designed. The gasifier was ignited by a flame torch and the composition of the producer gas was found in close agreement with the desired composition.

CHAPTER 3

GASIFICATION

3.1 BIOMASS

The organic matter produced by plants and their derivatives is termed as biomass. Forest crops and residues are also included under biomass. Biomass is considered as a renewable source of energy because plant life renews and adds to itself every year unlike conventional sources of energy. Biomass resources can be grouped under three categories. The first category is biomass in its traditional solid mass and the biomass is burned directly to obtain energy. The second category is biomass in its non-traditional form in which biomass is converted into methanol and ethanol to be used as liquid fuels in engines. The third category is to ferment the biomass to obtain a gaseous fuel termed bio-gas.

Wood waste and bagasse have potential of generating electricity. These biomasses are highly dispersed and bulky and contain large amounts of water. Hence, these must be converted to usable energy close to the source.

Wood chips and saw dust are currently used for domestic heating and to provide process heat in the timber and furniture industries. Wood has relatively low ash and sulphur content and burns easily. The amount of heat generated by one volume of coal is equivalent to that generated by four volumes of wood.[8]. The heat content of various fuels is shown in Table 2.

3.2 BIOMASS CONVERSION TECHNOLOGIES

A lot of technologies are available for biomass conversion to obtain premium fuels like digestion, fermentation and gasification as shown in Table 3 and Fig.1. Also, each biomass resource can be treated in a number of ways to obtain different kinds of products. For example, domestic refuse can be dried and burnt to provide heat or subjected to pyrolysis to get low calorific value gas. Also it can be stirred into slurry and digested to yield methane. A number of factors decide the process to be used like the location of the resource and its physical condition, the economics of the competing processes and the availability of a suitable market for the product. Biomass conversion can take many forms: (1) direct combustion such as wood waste and bagasse (2) thermo-chemical conversion and (3) biochemical conversion. Thermo-chemical conversion again consists of: gasification and liquefaction. [8]

Table 2. Heat content of various fuels[8]

	Fuel	**Heat content (approximate)**	**Unit**
Gas	Hydrogen	12	MJ/m^3
	Fuel gas	5-20	MJ/m^3
	Biogas	20-25	MJ/m^3
	Methane	38	MJ/m^3
Liquid	Methanol	21	GJ/m^3
	Ethanol	27	GJ/m^3
	Crude oil	44	GJ/m^3
Solid	Refuse	9	GJ/m^3
	Straw	16	GJ/m^3
	Wood(air dried)	12-15	GJ/m^3
	Wood(kiln dried)	20	GJ/m^3
	Char	20	GJ/m^3
	Coal	22-32	GJ/m^3

Table 3. Biomass Conversion Technologies [8]

<table>
<tr><th>Conversion process</th><th>Solids</th><th>Liquids</th><th>Gases</th><th>Further treatment</th><th>Premium fuels</th></tr>
<tr><td>Anaerobic digestion</td><td></td><td></td><td>Methane and carbon dioxide</td><td>Carbon dioxide removal</td><td>Methane</td></tr>
<tr><td>Fermentation</td><td></td><td>Ethanol</td><td></td><td>Distillation</td><td>Ethanol</td></tr>
<tr><td>Chemical reduction</td><td></td><td>Mixture of oils</td><td></td><td>Fractional distillation</td><td>Hydrocarbon liquids</td></tr>
<tr><td>Liquefaction</td><td>Char</td><td rowspan="2">Pyroligneous acids, oils and tars</td><td rowspan="2">Fuel gas</td><td rowspan="2">Steam reforming and/or shift reaction</td><td>Methane</td></tr>
<tr><td>Gasification</td><td>Char</td><td>Methanol or higher alcohols</td></tr>
</table>

In gasification the biomass is heated with limited oxygen to produce low heating value gas or made to react with steam and oxygen at high pressure and temperature to produce medium heating value gas. Biochemical conversion can be divided into two forms: anaerobic digestion and fermentation. Microbial digestion of biomass is termed anaerobic digestion. This process occurs at low temperature and requires 80% moisture content. The gas produced mainly consists of CO_2 and Methane. The gas can be burned directly or used as synthetic natural gas by removing CO_2 and other impurities. In fermentation, complex molecules in an organic compound are broken under the influence of a ferment such as yeast, bacteria etc. It is widely used for converting sugar crops into ethanol.

The various biomass conversion processes fall under two categories:

(1) Wet processes: The following are the various forms of wet processes:

(a) Anaerobic digestion: The bacterial decomposition of wet sewage sludge, animal dung or green plants in the absence of oxygen leads to the production of biogas. Anaerobic decomposition can be speeded up by using a thermally insulated, air-tight tank with stirrer unit and heating system. The gas which is collected in the digester tank can be piped off continuously

(b) Fermentation: The fermentation of sugar solution by natural yeasts produces ethanol. The fibrous residues from plant crops like sugarcane bagasse have been burnt to provide the heat traditionally. The feedstocks suitable for this purpose are crushed sugarcane, beet, fruit etc.

(c) Chemical reduction: Of all the wet biomass conversion processes, it is the least developed. Here, animal wastes are pressure-cooked with an alkaline catalyst in the presence of carbon monoxide. Thus the organic material is converted into a series of oils.

(2) Dry processes: The following are the various methods of dry biomass conversion:

(a) Pyrolysis: This involves roasting dry woody matter like straw and woody chips. The material in a pulverized or shredded form is fed into a reactor vessel or retort and heated in the absence of air. Under the effect of high temperature, the cellulose and lignin break down to simpler substances.

(b) **Liquefaction:** Rapid heating of feedstock to comparatively low temperatures gives liquid yields. The vapors are condensed from the gas stream. These separate into two phase liquor: the aqueous phase contains a soup of water-soluble organic materials like acetic acid, acetone; the non-aqueous phase consists of oils and tars.

(c) **Gasification:** Here, small quantities of air or oxygen are blown into the reactor vessel and the temperature is increased to over 1000^0C. This causes part of the feed to burn.

(d) **Steam gasification:** By treating with hydrogen gas, Methane is directly produced from woody matter by treatment at high temperatures and pressures. The hydrogen can be generated in the reactor vessel from carbon monoxide and steam.

(e) **Hydrogenation:** In this process, carbon monoxide and steam react with cellulose to produce heavy oils under less severe conditions of temperature and pressure. These oils can be separated and refined to produce premium fuels. [8]

3.3 THERMAL GASIFICATION OF BIOMASS

The term *gasification* implies converting a solid or liquid into a gaseous fuel without leaving any carbonaceous residue. A **gasifier** is an equipment which can gasify a variety of biomass such as wood waste, agricultural waste like stalks and roots of various crops. Various complex physical and chemical processes take place in the gasifier which acts as a chemical reactor. The biomass gets heated, pyrolysed, partially oxidized and reduced, as it flows through it. The gas that is produced in a gasifier is a clean-burning fuel having heating value of about 950-1200 kcal/ m^3. Hydrogen and carbon monoxide are the main constituents of the gas. Methods of converting biomass into useful forms of energy can be broadly classified as biochemical and thermochemical methods. The biochemical route of conversion of biomass to other useful forms relies upon the action of bacteria which degrade complex molecules of biomass into simpler ones. It is a low energy process. An example of this process is the production of biogas by anaerobic digestion. In thermochemical methods, the biomass is raised to high temperatures and depending upon the availability of oxygen processes such as pyrolysis, combustion and gasification occur. Direct burning of biomass in stoves is an example of combustion in which the supply of oxygen is higher than required stoichiometrically. Pyrolysis and gasification occur under the conditions of lower rates of oxygen supply. In a gasifier, a solid fuel is converted by a series of thermo-chemical processes to a gaseous fuel-producer gas. If atmospheric air is used as gasification agent, the producer gas consists mainly of carbon monoxide, hydrogen and oxygen. A typical composition of the gas obtained from wood gasification on volumetric basis is given below[8]:

Carbon monoxide	18 - 22%
Hydrogen	13 - 9%
Methane	1 - 5%
Heavier hydrocarbons	0.2 - 0.4%
Carbon dioxide	9 -12%
Nitrogen	45 - 55%
Water vapor	4%

The gas produced can be used either in dual fuel engines or in diesel engines with some modification for the generation of power. Engines operation on a spark ignition system (e.g. petrol engines) can be made to run entirely on producer gas, whereas those using compression ignition systems (e.g. diesel engines) can be made to operate with about 60%-80% fuel oil replacement by the gas. In larger systems, the gas can be burnt directly (e.g. in an industrial oil fired boiler).

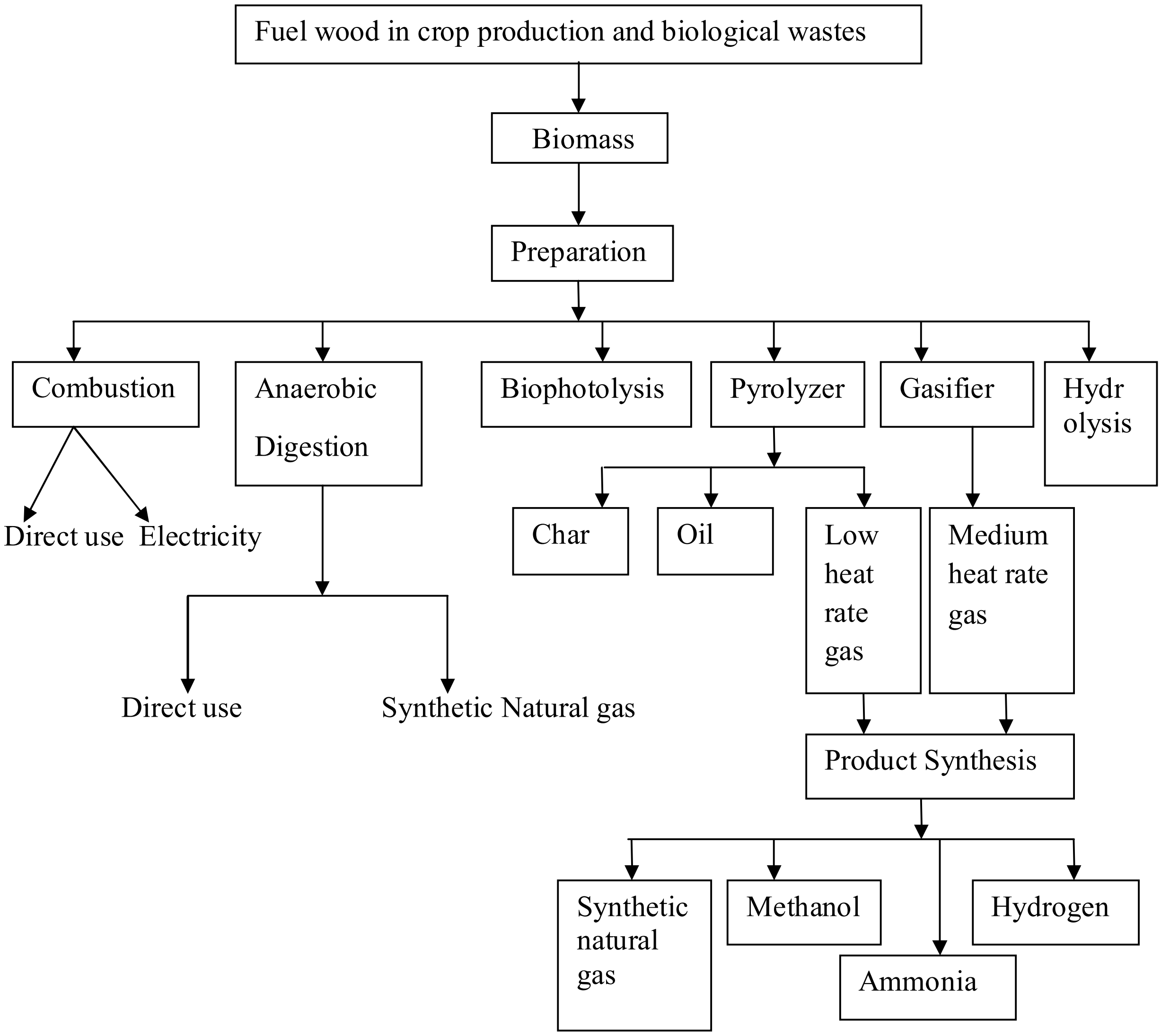


Fig.1. Possible energy conversion routes and products from biomass[8]

Excess air or at least 100% theoretical air is required for complete combustion to take place, whereas gasification takes place with excess carbon. The gasification of solid fuels containing carbon is accomplished in an air sealed, closed chamber under slight vacuum or pressure relative to ambient pressure. The fuel column is ignited at one point and exposed to the air blast. The gas is drawn off at another location. Depending upon the positions of air inlet and gas withdrawal with reference to the fuel bed movement, three types of gasifiers have been designed and operated to date they are: (a) updraft, (b) down-draft and (c) cross draft gasifiers.

The advantages of a gasifier are:

i. It is very easy to operate the gasifier.

ii. Its maintenance is easy.

iii. It is study in construction and,

iv. Reliable in operation

Gasification is a suitable conversion alternative in view of the following reasons:

1. Gasification involves high flexibility in terms of various biomass materials as feedstock.
2. Gasification has thermochemical conversion efficiencies in the range of 70% to 90%.
3. Gasification output capacity is controlled only by the availability of adequate feed materials rather than on other technical considerations.
4. The area requirement of gasification equipment is lowest per unit output of energy in the form of heat and/or electricity.
5. The gasification equipment has high turndown ratios comparable to biogas and higher than steam turbine systems.
6. Gasification outputs are suitable as a fuel to all types of internal combustion engines[8]

3.4 CLASSIFICATION OF BIOMASS GASIFIERS

Gasifiers are classified as per:

(i) The direction of gas flow

(ii) The output or capacity of the gasifiers.

Gasifier is a vertical flow packed bed reactor through which oxygen or air for combustion is passed. It may pass upward or downward or across the bed. The direction of the gas flow defines it as a down draft, up draft or cross draft producer gas generator.

As per the output power gasifiers are classified as

► Small size gasifiers with output upto 10 kW.

► Medium size gasifiers with outputs in the range of 10 kW to 50 kW.

► Large size gasifiers with output in the range of 50 kW to 300 kW.

► Very large size gasifiers with outputs of 300 kW and above.

The three main designs of fixed bed gasifiers are (i) updraft gasifiers (ii) downdraft gasifiers and (iii) cross draft gasifiers.[8]

3.4.1 UPDRAFT GASIFIER

In updraft gasifier air enters below the combustion zone and the producer gas leaves near the top of the gasifier. This type of gasifier is easy to build and operate. The gas produced contains tar and water vapor because of passing of gas through the unburnt fuel. The gas produced has practically no ash. Thus, updraft gasifiers are suitable for tar free fuels like charcoal especially in stationary engines. In the present work, an updraft gasifier has been designed and built because of its ease of manufacturing. The schematic diagram of an updraft gasifier is shown in Fig.1.[8]

3.4.2 DOWNDRAFT GASIFIER

In this type of gasifier, air enters at the combustion zone and the gas produced leaves near the bottom of the gasifier. In this type of gasifiers, the volatiles and the tars produced from the descending fixed-bed have to pass through the reaction zone where mostly they are racked and gasified. The throat that acts like a constriction provided in the hearth ensures that the gaseous products pass through the hottest zone, the gas produced contains less of tar and more of ash. In the downdraft gasifier, air enters through radial tuyers near the top of the fire box. The partial combustion takes place in the zone in front of the tuyere openings. The heat generated pyrolyzes the fuel immediately above and the hot gases proceed downward through the firebox construction, and exit through the grate. [8]. The gasification process in downdraft gasifier is shown in Fig.2.

3.4.3 CROSS DRAFT GASIFIER

In this type of gasifiers, the gas produced passes upwards in the annular space around the gasifier that is filled with charcoal. The charcoal acts as an insulator and a dust filter. They are usually suitable for power generation upto 50 kW. Air enters the cross draft gasifier through a water cooled nozzle mounted on one side of the firebox. The gas is produced in the horizontal zone in front of the nozzle and passes through a vertical grate into the hot gas port on the opposite side. Its schematic diagram is shown in Fig.3.[8]

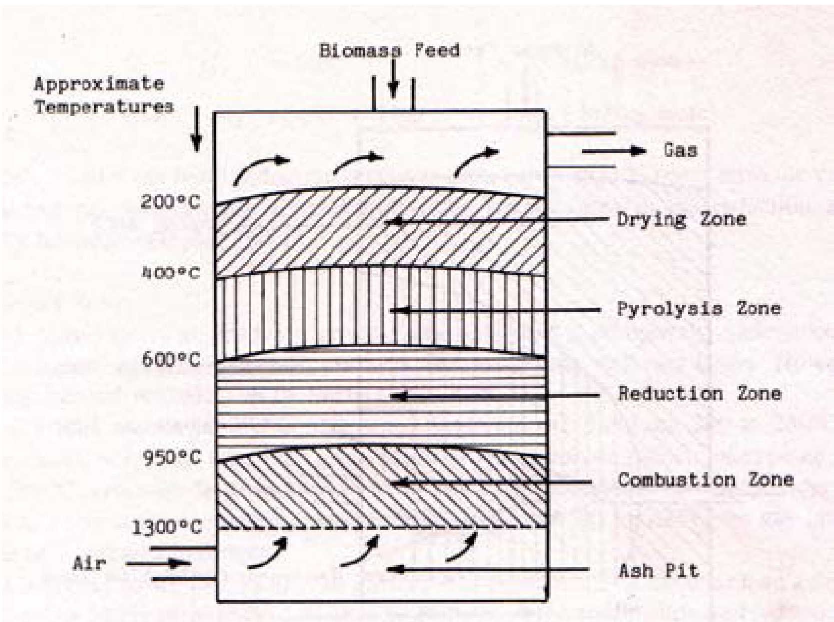


Fig.2. Schematic diagram of an updraft gasifier showing the different zones [9]

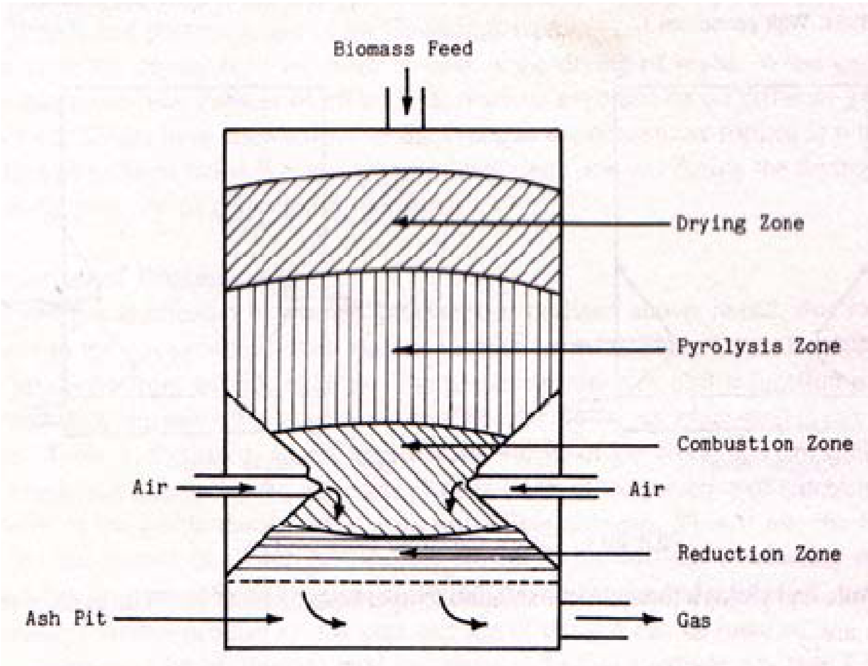


Fig.3. Gasification process in downdraft gasifier[9]

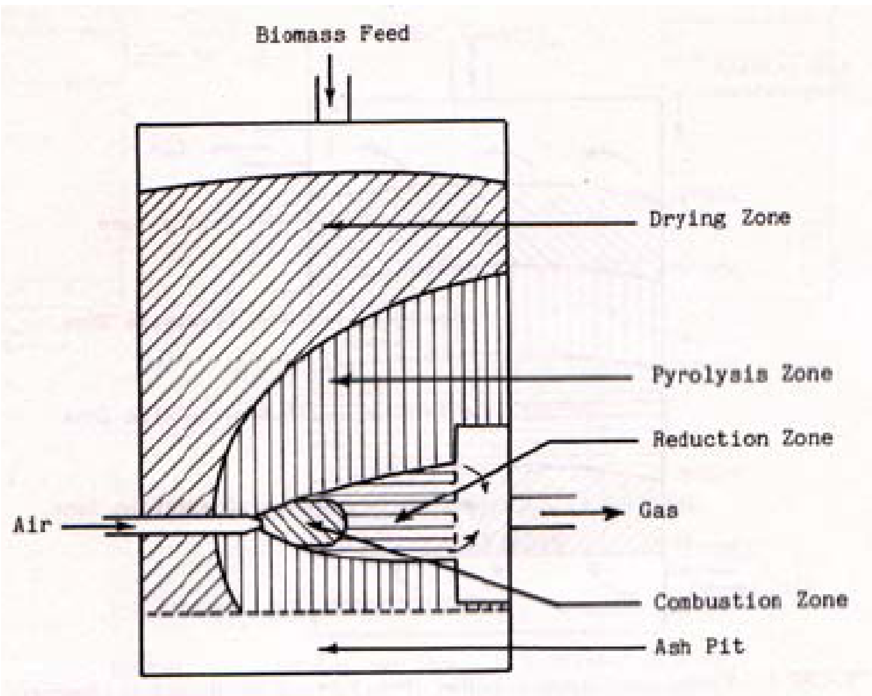


Fig.4. Gasification process in cross draft gasifier[9]

The various applications of the gasifier are shown in Fig.5.

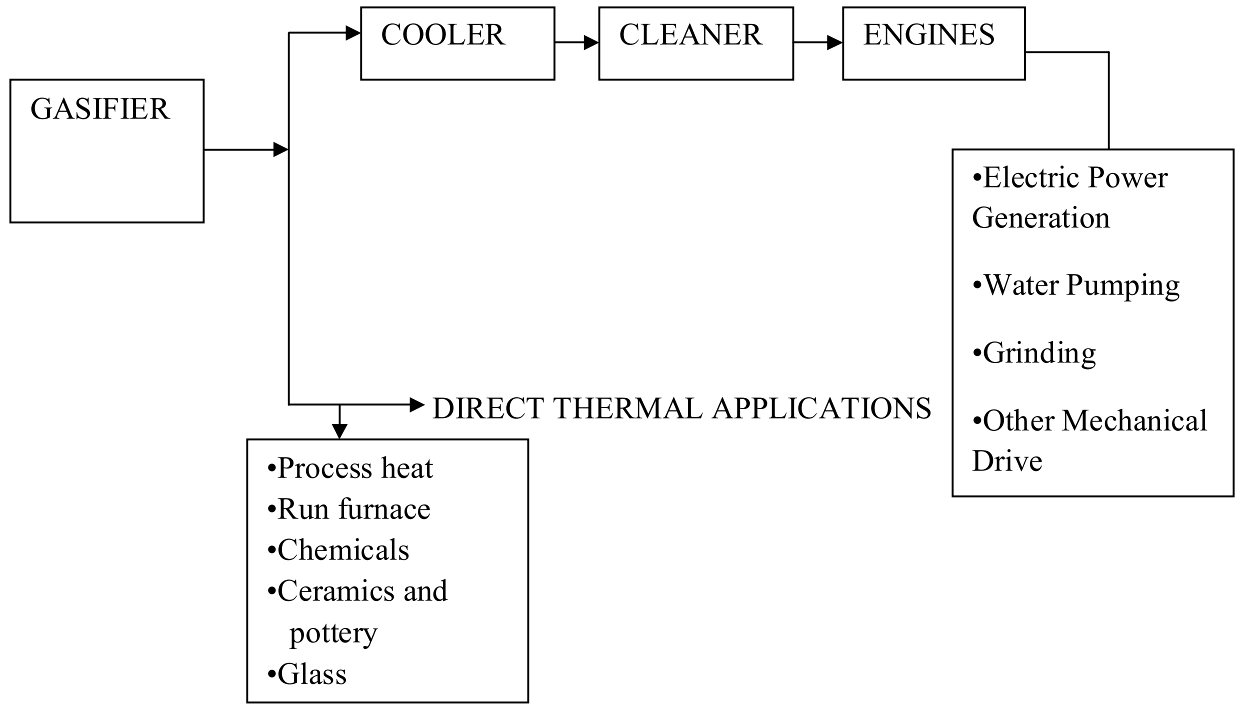


Fig.5. Various applications of the gasifier[8]

3.5 CH\EMISTRY OF THE GASIFICATION PROCESS

The following are the major reactions taking place in the different zones of the gasifier.

1. Combustion zone

The combustible substance of a solid fuel is usually composed of elements carbon, hydrogen and oxygen. In complete combustion carbon dioxide is obtained from carbon in fuel and water is obtained from the hydrogen, usually as steam. The combustion reaction is exothermic and yields a theoretical oxidation temperature of 1450°C. The main reactions, therefore, are[9]:

$C + O_2 = CO_2$ (+ 393 MJ/kg mole) (1)

$2H_2 + O_2 = 2H_2O$ (- 242 MJ/kg mole) (2)

2. Reduction zone

The products of partial combustion (water, carbon dioxide and uncombusted partially cracked pyrolysis products) now pass through a red-hot charcoal bed where the following reduction reactions take place.

$C + CO_2 = 2CO$ (- 164.9 MJ/kg mole) (3)

$C + H_2O = CO + H_2$ (- 122.6 MJ/kg mole) (4)

$CO + H_2O = CO + H_2$ (+ 42 MJ/kg mole) (5)

$C + 2 H_2 = CH_4$ (+ 75 MJ/kg mole) (6)

$CO_2 + H_2 = CO + H_2O$ (- 42.3 MJ/kg mole) (7)

Reactions (3) and (4) are main reduction reactions and being endothermic have the capability of reducing gas temperature. Consequently the temperatures in the reduction zone are normally 800-1000°C. Lower the reduction zone temperature (~ 700-80°C), lower is the calorific value of gas.[9]

3. Pyrolysis zone

Wood pyrolysis is an intricate process that is still not completely understood. The products depend upon temperature, pressure, residence time and heat losses. However following general remarks can be made about them.

Upto the temperature of 200^0C only water is driven off. Between 200°C to 280°C carbon dioxide, acetic acid and water are given off. The real pyrolysis, which takes place between 280°C to 500°C, produces large quantities of tar and gases containing carbon dioxide. Besides light tars, some methyl alcohol is also formed. Between 500°C to 700°C the gas production is small and contains hydrogen.

Finally in the **drying zone** the main process is of drying of wood. Wood entering the gasifier has moisture content of 10-30%. Various experiments on different gasifiers in different conditions have shown that on an average the condensate formed is 6-10% of the weight of gasified wood.

Some organic acids also come out during the drying process. These acids give rise to corrosion of gasifiers.[9]

CHAPTER 4

DESIGN AND DEVELOPMENT OF THE GASIFIER

4.1 COMPONENTS OF THE FABRICATED GASIFIER:

The various parts of the fabricated gasifier and their methods of manufacturing are described below:

1.**Reaction chamber**: It is the most crucial part of the gasifier. The material used for constructing the outside wall of the reaction chamber was 2 mm thick mild steel sheet and the outside dimension of the reactor was 36x36x44 cm. Thus, the bottom plate had a dimension of 36x36 cm; the other mild steel plates had a dimension of 36x44 cm. All these plates were welded on both sides with each other to make a box-like structure. The inside wall was made with the help of refractory bricks and these were cemented with castable clay. Eighteen refractory bricks were used for this purpose. The inside dimension of the reactor was 16x16x22 cm. The grate on top of which fuel was placed was kept at a height of 22 cm from the top and the reaction chamber was supported by four legs. The chips of wood were placed on the grate and filled to nearly two-thirds the height of the gasifier. The grate was made by parallel steel bars of diameter 6 mm with 1 cm spacing in between. The ash that was formed could be suitably collected in an ash collector and fall down freely through the grate. For removing the accumulated ash, a mild steel door was provided at one side of the reaction chamber. This door was also used to ignite the fuel. The dimension of the door was 18x18 cm. It was fixed to the reaction chamber with the help of a hinge that was welded to the chamber. The ash could be removed periodically through this door. The top plate of the reaction chamber which had a dimension of 36x36 cm had a hole drilled in it so that the fuel hopper could be attached to it. The dimension of the hole was chosen to be 20 cm. The figure 4 shows the design details of the reaction chamber.

2.Air inlet: The air inlet was attached to one side of the reaction chamber. It was made of a pipe of mild steel material and had 2 " diameter. The above dimension was chosen so that it could easily fit with the pipe coming out from the blower available at the laboratory. It was fixed to the reaction chamber through threaded connections and was placed slightly below the grate. The figure 5 shows a schematic sketch of the air inlet.

3.Fuel hopper: It was made of mild steel sheet and was located above the reaction chamber. The fuel storage hopper had a height of around 80 cm and a circular cross section with a diameter of 20 cm. Circular cross section was chosen as it did not have problems of the fuel being stuck at the corners. It was made by preparing two half sections and then welding them on both sides. A gasket was used to tightly fit this circular hopper to the reaction chamber. The top plate was again tightly fitted with the help of a gasket and nuts and bolts were used for fitting. The figure 6 shows the design details of the fuel hopper.

4. Gas outlet: The producer gas formed in the reaction chamber was allowed to pass out through a ½ " diameter mild steel pipe. Two ½ " elbows were also used for achieving the design as shown in figure 7. Another pipe was drawn off from the main pipe that had a gas valve to suitably control the amount of gas coming out. A small pipe was provided with one end kept open to the atmosphere so that in case of any kind of emergency the gas would be simply allowed to exit to the atmosphere. Another valve and pipe arrangement was provided at the bottom for dust filtration

4.2 GASIFICATION USING WOOD CHIPS

Wood chips (sesame wood or rose wood) were used as fuel which is a renewable form of energy and reduces damage to the environment. Further, these chips could be easily obtained from workshops. Table 3 lists the physical properties of sesame wood while Table 4 lists the proximate analyses of sesame wood.

Table 4. Physical properties of sesame wood chips[4]

Absolute density, (kg/m^3)	1170
Bulk density, (kg/m^3)	605
Higher heating value (dry basis) (MJ/kg)	18.06

Table 5. Proximate analysis of sesame wood[4]

Volatile matter, (%)	80.40
Fixed carbon, (%)	15.70
Ash, (%)	3.90

In the gasification, wood chips were used as the feed stock or the raw material. The wood chips were sun-dried for two days to get rid of excess moisture. The ignition temperature is produced by auxiliary burners. Air is injected into the gasifier from the bottom side .The gas is released from the top.

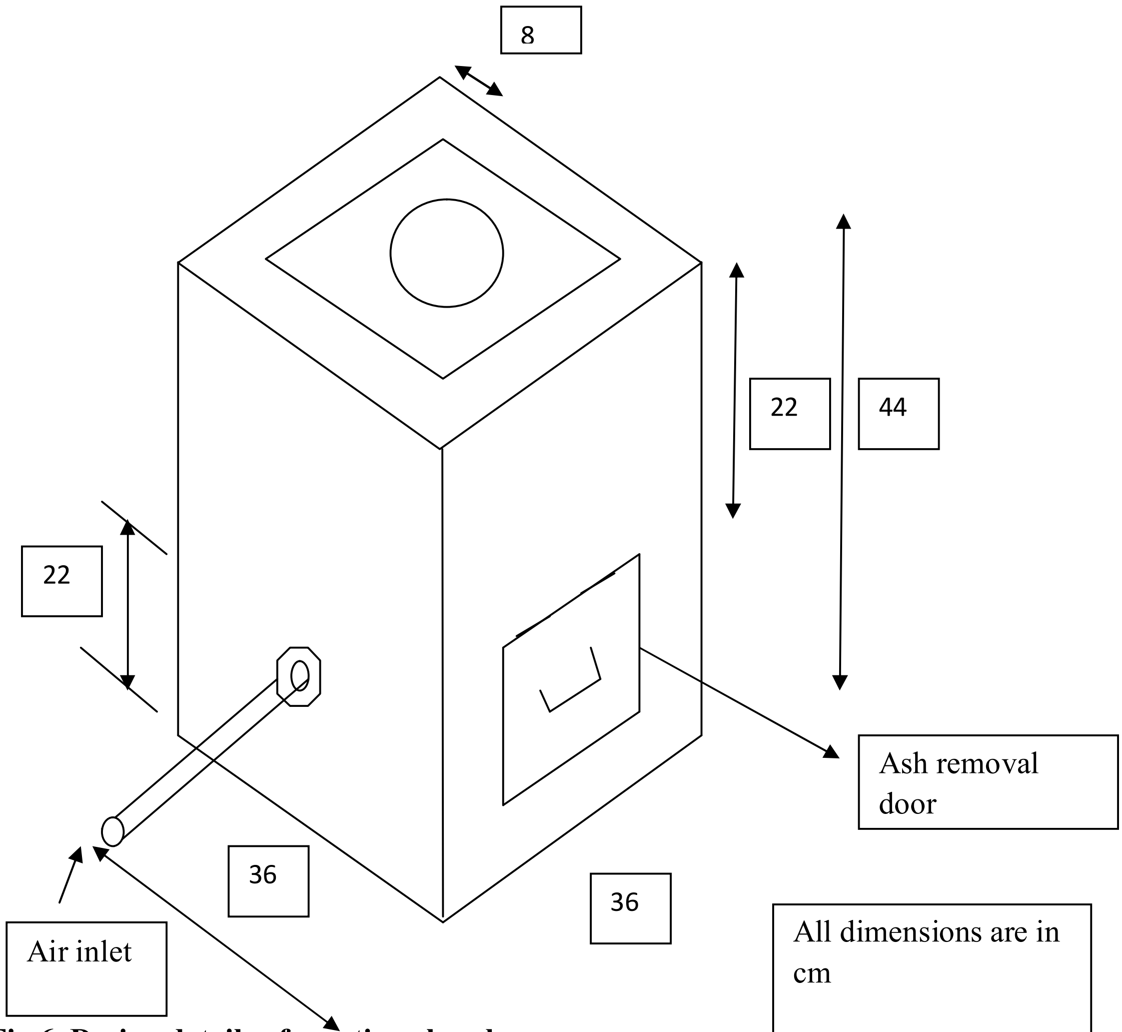


Fig.6. Design details of reaction chamber

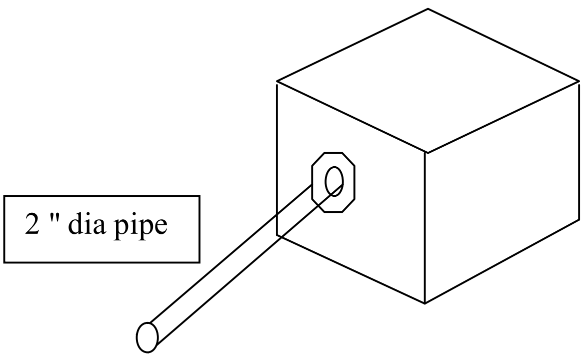
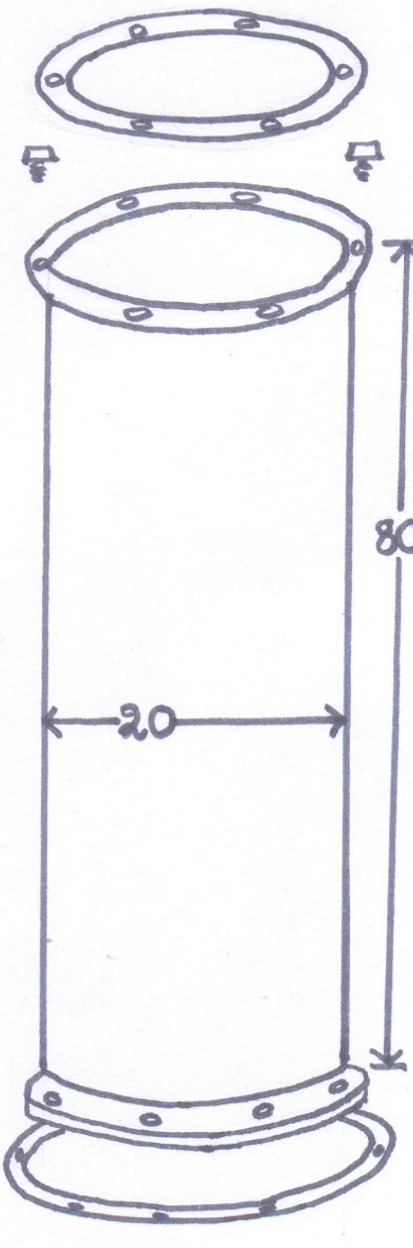


Fig.7. Design details of air inlet



All dimensions
are in cm

Fig.8. Design details of fuel hopper

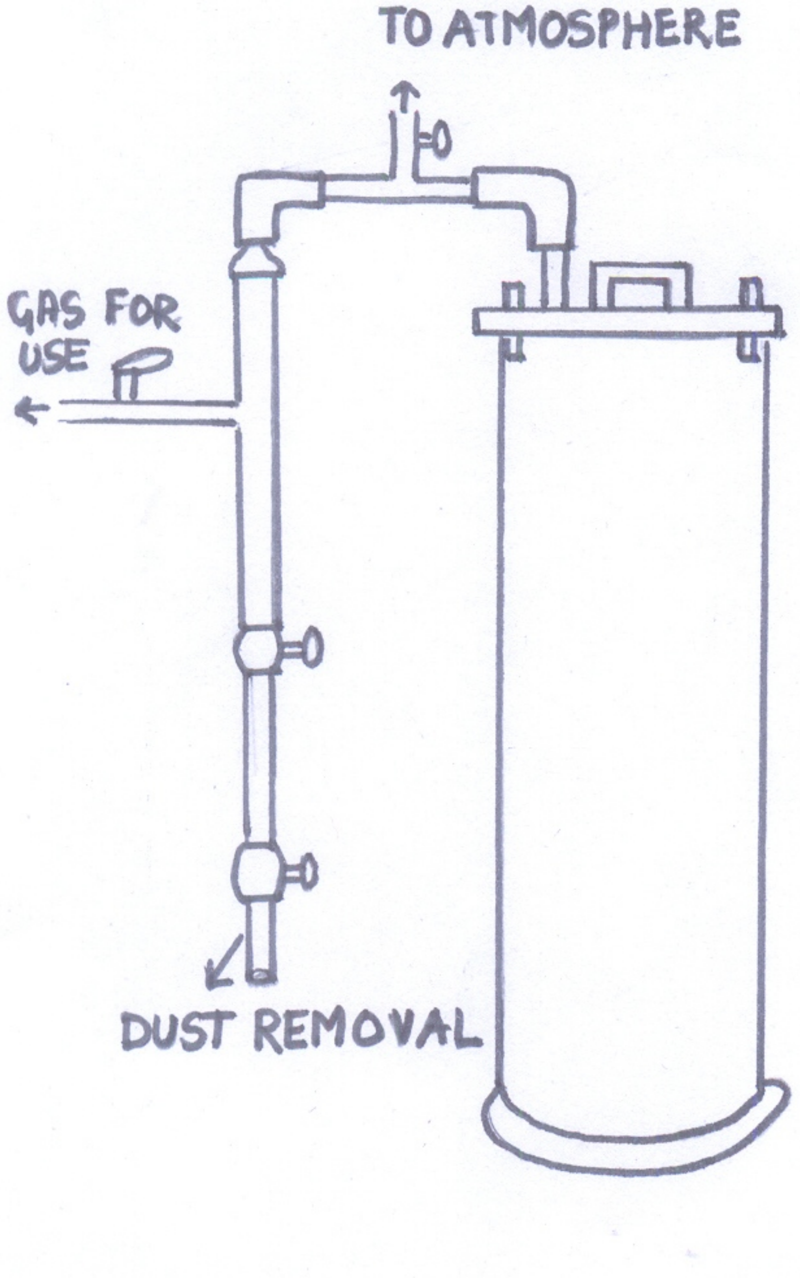


Fig.9. Sketch of the gas outlet connections and valves used

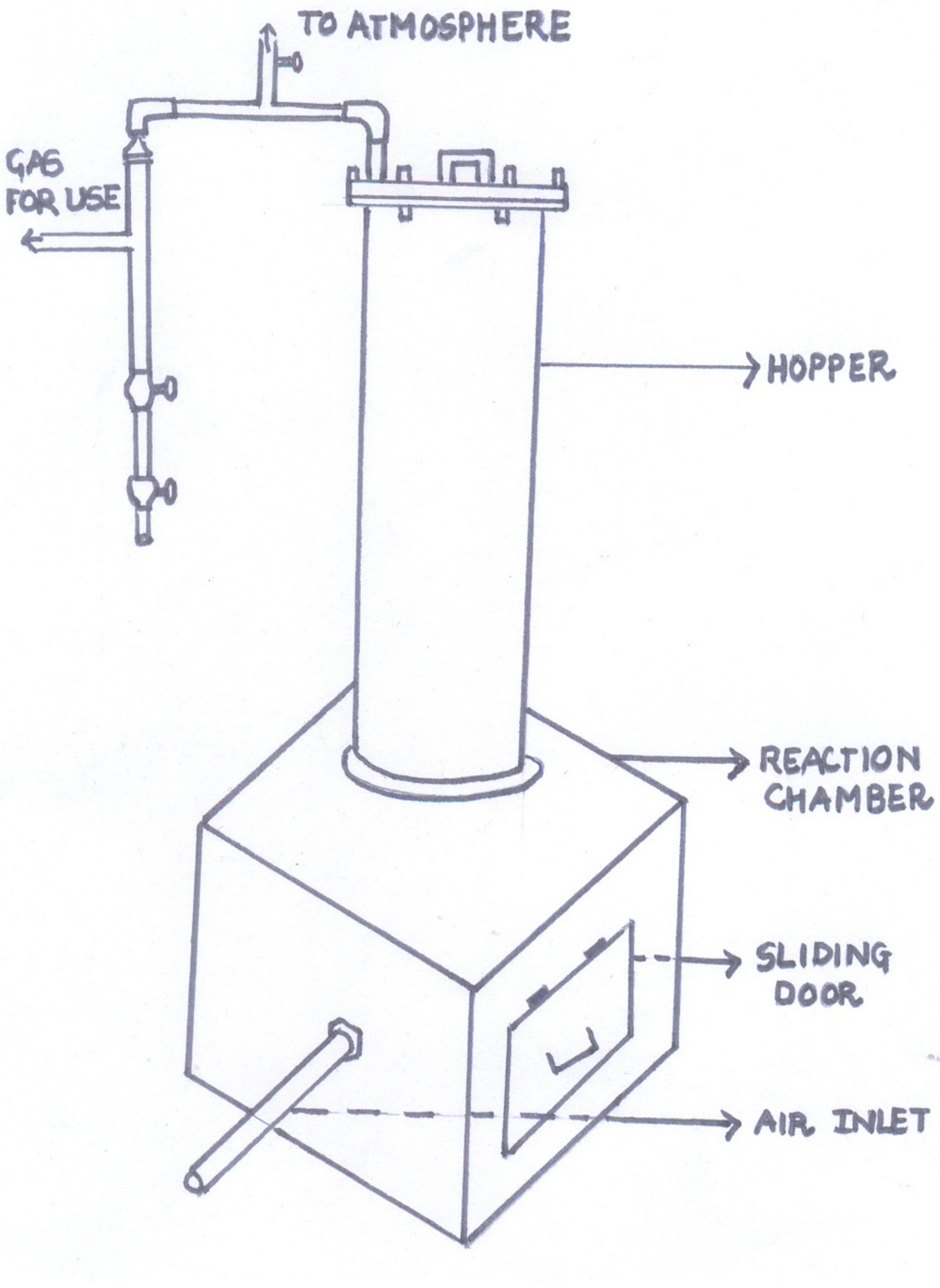


Fig.10. Sketch of the complete gasifier

Fig.11. The reaction chamber **Fig.12. The sliding door for ash removal**

Fig.13. Reaction chamber lined with castable refractory and showing the grate

Fig.14. The fuel hopper

Fig.15. The air inlet

Fig.16. The gas outlet pipe connections and the valves

Fig.17. The complete gasifier

CHAPTER 5

EXPERIMENTATION

5.1 EXPERIMENTAL SETUP:

The air supply is given by a blower and regulated by a valve. The pipe coming out from blower is fitted with the air inlet on one side of the reaction chamber. The arrangement of the experimental setup is shown in Fig16. As shown in the figure, a red pipe coming out of the gasifier is directed to the diesel engine. After assembling the gasifier unit with the blower and the diesel engine, the experiments are conducted further. The gas coming out from the gasifier is allowed to pass through a condenser and is directed to the heat engine.

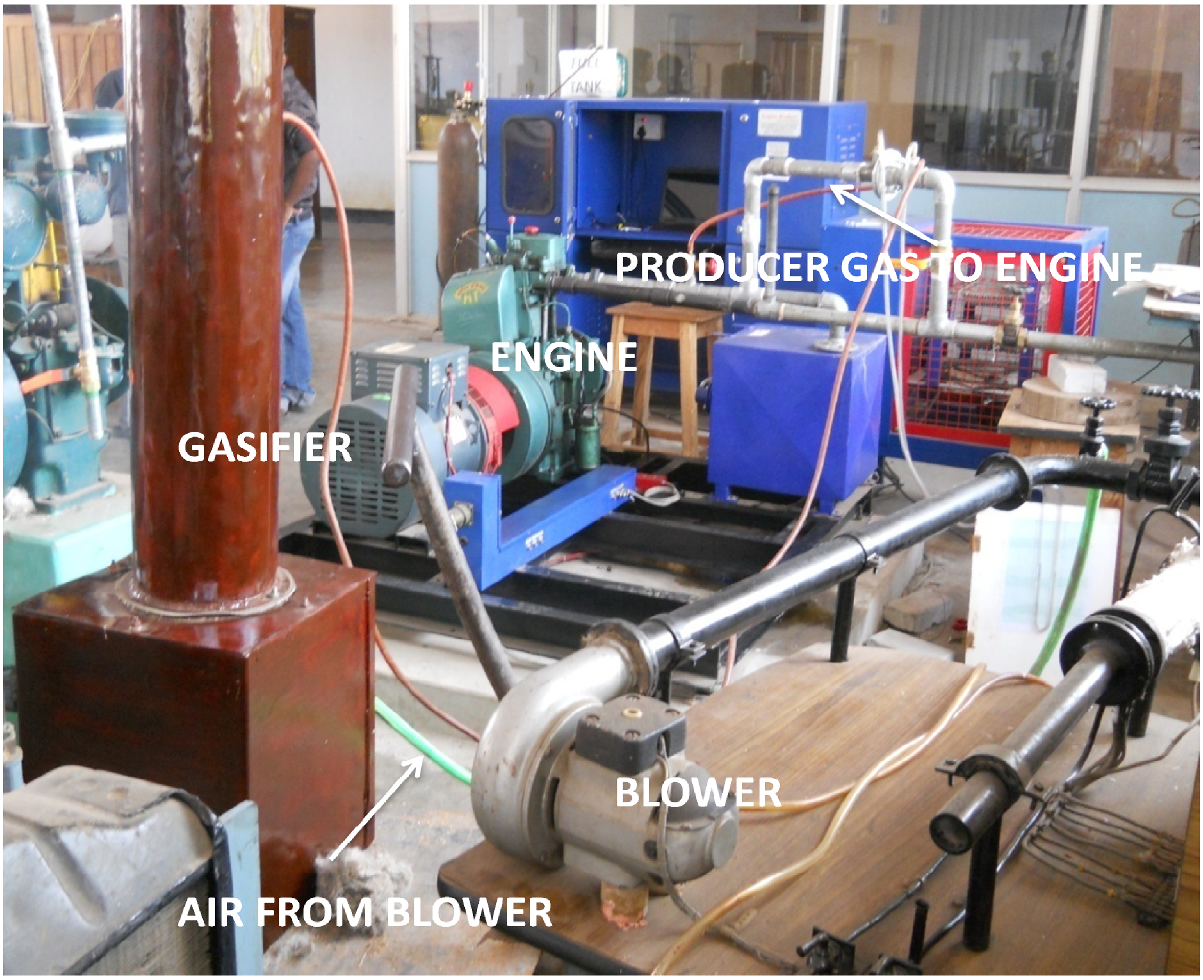


Fig.18. The experimental setup

The specifications of the engine and the values of various parameters are given below:

The engine under consideration is a Kirloskar diesel engine, TAF 1 model, 4-stroke single cylinder, direct injection and air cooled engine.

Speed of the engine= 1500 rpm. Bore of the cylinder is80 mm and stroke length is 110 mm.

Injection occurs 23 ° before Top dead centre. (TDC)

Maximum brake power= 4.4 kW.

Flow rate of the gas= 1 litre/minute.

Density of diesel= 0.86 kg/m^3

Calorific value of diesel= 44.2kJ/kg

Calorific value of producer gas= 500kJ/kg[16]

Density of producer gas= 1kg/m^3

Fig.19. Initial running of the gasifier

Initially the fuel is ignited with the help of liquefied petroleum gas (LPG) and auxiliary burners. The initial ignition takes around 40 minutes and the gas is allowed to come out through the pipe opening at the atmosphere. After a continuous supply of white gas is observed coming out, the topmost valve is closed and the gas outlet valve directed towards the engine is opened. The diesel engine is started and air along with the gas is sent to the engine. Various parameters of the engine are noted further.

CHAPTER 6

RESULTS AND DISCUSSION

6.1 PERFORMANCE CHARACTERISITCS

Internal combustion engines are found to operate within a certain range of speed. The power output varies within the useful range at each speed and it has a maximum usable value. The ratio of the power developed to the maximum usable power at the same speed is called the load. The specific fuel consumption varies with load and speed. The relationship between power developed, specific fuel consumption and speed is crucial and determines the performance of the engine. The useful mechanical energy available at the shaft is termed the **brake power.** A power absorption device attached to the drive shaft of the engine measures the BP. The forces delivered by the engine are counteracted by the measurable forces set up by the device. The value of these measured forces is indicative of the brake power of the engine.[1]

6.1.1. BRAKE THERMAL EFFICIENCY

It is the ratio of energy in the brake power, BP, to the input fuel energy in appropriate units. The brake thermal efficiency gives an indication of the output generated by the engine as compared to the heat supplied to the engine. This heat is derived from burning of the fuel.

$\eta_{bth} = \mathrm{BP}/((\text{Mass of fuel})/\mathrm{s} * \text{ calorific value of fuel}),$

where η_{bth} is the brake thermal efficiency.[1]

The Fig.20 gives a comparison between the brake thermal efficiencies of the engine when only diesel is used as the fuel and when both diesel and producer gas are used. The brake thermal efficiency is plotted as a function of brake power. When producer gas is used along with fuel a notable increase in efficiency can be observed at the different power outputs. This might be due to the fact that the producer gas adds energy to the air stream that is injected into the diesel engine.

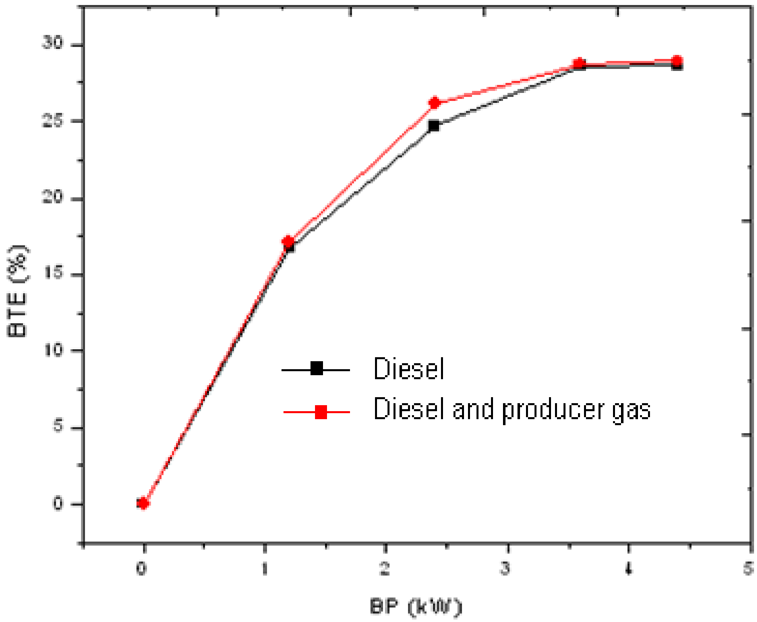


Fig.20. Graph showing the variation of brake thermal efficiency with brake power

6.1.2 EXHAUST GAS TEMPERATURE

It is an indication of how effectively the input energy is converted to work. When the exhaust gas temperature is high, the mixture is supposed to be leaner. The Fig.21 shows the variation of exhaust gas temperature with brake power for both diesel as the fuel and diesel along with producer gas. It is observed that the exhaust gas temperature when we are using diesel along with producer gas is higher than when we are using simply diesel at all power outputs. This may be due to the fact that the energy supplied to the engine increases when we are sending producer gas along with air. Also, the higher exhaust gas temperature is an indication of the increase in NO_x emissions.[10,13]

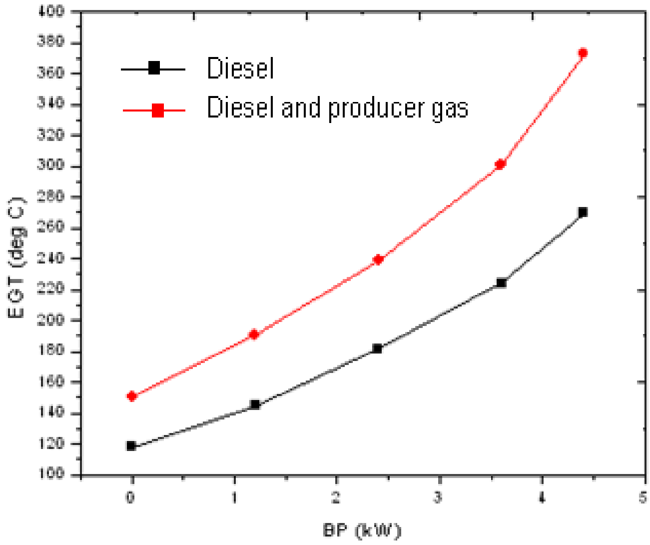


Fig.21. Graph showing the variation of Exhaust gas temperature with Brake power

6.1.3 BRAKE SPECIFIC ENERGY CONSUMPTION

Brake specific fuel consumption (bsfc) is the fuel consumed per unit brake power.

$$bsfc = \frac{m_f}{BP}$$

where, m_f is the mass of fuel consumed per unit time and BP is the brake power. **Brake specific energy consumption (bsec)** is the energy consumption per unit brake power.

$$bsec = bsfc * q_{cv}$$

where q_{cv} is the calorific value of the fuel.

The Fig.22. shows the variation of brake specific fuel consumption with brake power when diesel is used as a fuel and when producer gas is sent along with air. The specific energy consumption is found to decrease at all power outputs when diesel along with producer gas is used which is an indication of good combustion efficiency. The use of producer gas reduces the consumption of diesel fuel at all power outputs.

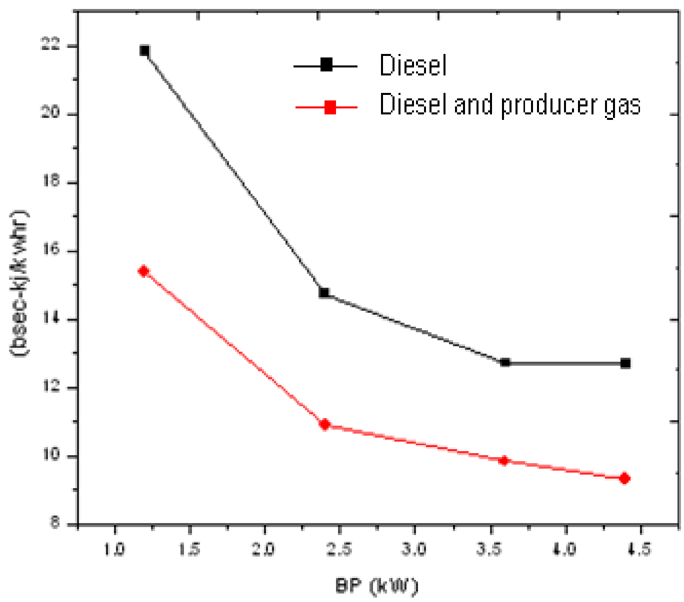


Fig.22. Graph showing the variation of Brake specific energy consumption with brake power

6.2 COMBUSTION CHARACTERISTICS

6.2.1 IGNITION DELAY

The fuel does not ignite immediately upon injection into the combustion chamber. There is a certain time lag between the injection of the fuel and the start of the actual burning. This time lag is termed as **ignition delay**. In Fig.23, a comparison is shown between the ignition delay when only diesel is used and when both diesel and producer gas are used as fuel. At lower and higher power outputs, the ignition delay is found to be less when producer gas is sent along with air. The trend observed is not very conclusive. As the power increases the ignition delay decreases when producer gas along with diesel is used. This might be due to more effective utilization of air when producer gas is used and thus reducing the time lag.

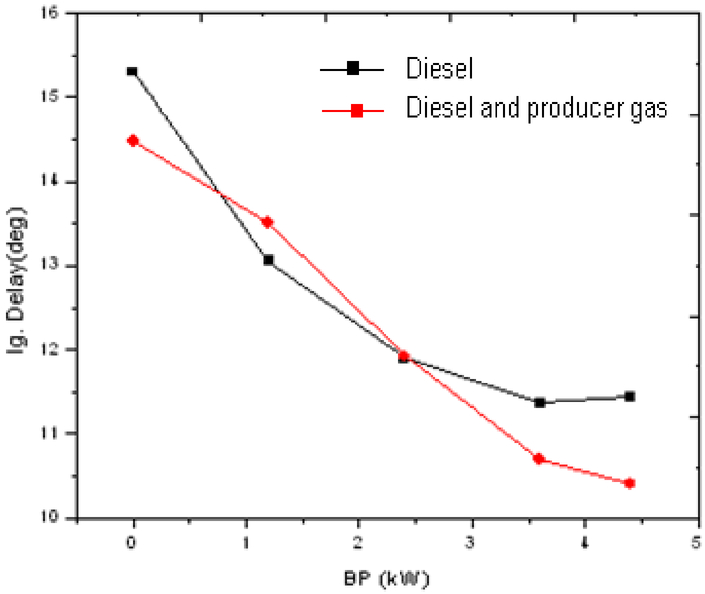


Fig.23 . Graph showing the variation of Ignition delay with brake power

6.2.2 MAXIMUM PRESSURE

The maximum pressure attained is directly proportional to the power output of the engine. The Fig. 24. shows the maximum pressure attained when diesel is used as the fuel and when both diesel and producer gas are used. The maximum pressure is found to increase when diesel along with producer gas is used. The addition of producer gas increases the energy content of the fuel which leads to increase in value of maximum pressure. Also, a higher value of ignition delay at 1.2 kW power output could lead to higher maximum pressure at this power output. More amount of fuel would have accumulated during the delay period.

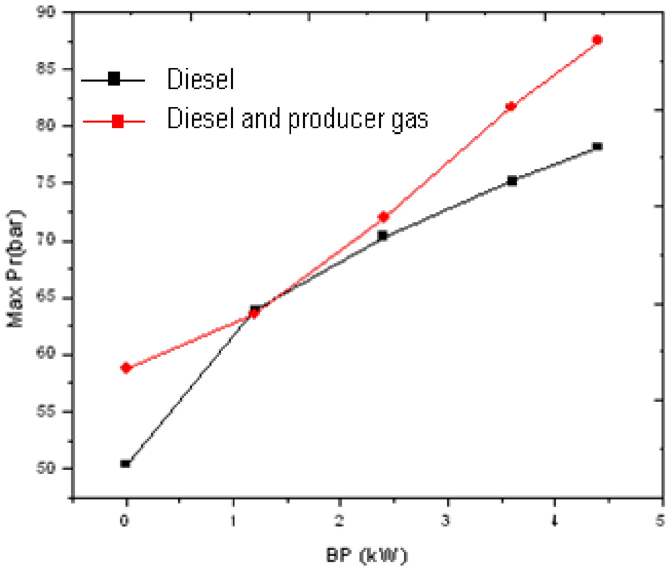


Fig.24. Graph showing the variation of maximum pressure with brake power

6.3 SUMMARY OF PERFORMANCE PARAMETERS

The Table 6 shows the readings obtained to denote the performance characteristics of the engine when diesel was used as the fuel and when producer gas was sent along with air. These readings were used to obtain the plots of performance characteristics as shown in Fig.20, Fig.21 and Fig. 22.

6.4 SUMMARY OF COMBUSTION PARAMETERS

The Table 7 shows the readings obtained to study the combustion characteristics of the engine when diesel was used as fuel. It also shows the changes in the parameters when producer gas was used along with diesel fuel. These readings were used to obtain the graphs to study the combustion characteristics shown in Fig.23 and Fig. 24

Table 6. Performance characteristics of diesel engine with diesel as the fuel and diesel along with producer gas as the fuel

Load (%)	Brake Power, BP(kW)	Brake Thermal Efficiency,BTE(%)		Exhaust Gas Temperature,EGT(°C)		Brake Specific Energy Consumption, bsec(kj/kWhr)	
		Diesel	**Diesel and producer gas**	**Diesel**	**Diesel and producer gas**	**Diesel**	**Diesel and producer gas**
0	0	0	0	118.210	150.584	Infinity	Infinity
25	1.2	16.724	17.122	144.872	190.815	21.816	15.355
50	2.4	24.689	26.137	181.552	239.342	14.715	10.884
75	3.6	28.603	28.759	223.870	301.018	12.701	9.831
100	4.4	28.645	28.908	269.599	372.723	12.687	9.303

Table 7. Combustion characteristics of diesel engine with diesel as the fuel and diesel along with producer gas as the fuel

Load (%)	Brake Power, BP(kW)	Ignition Delay (°)		Maximum Pressure (bar)	
		Diesel	**Diesel and producer gas**	**Diesel**	**Diesel and producer gas**
0	0	15.299	14.482	50.357	58.745
25	1.2	13.049	13.508	63.848	63.506
50	2.4	11.898	11.917	70.353	71.942
75	3.6	11.368	10.699	75.174	81.699
100	4.4	11.436	10.408	78.171	87.510

6.5 CONCLUSIONS

An attempt has been made in developing a gasifier and utilizing it to run a diesel engine.

- The gasifier was fabricated according to the designs drafted. The initial ignition of the gasifier did not sense any kind of leakage from any part. A white colored gas coming out could be detected.
- From the graphs and tables it is clear that with diesel as the main fuel along with producer gas, there is a marginal increase in brake thermal efficiency which is a positive sign. At maximum power output (full load), the brake thermal efficiency increases by 0.91%.
- Also, the brake specific energy consumption is found to decrease when producer gas is used along with diesel At full load conditions, the brake specific energy consumption decreases by 26.67%.

The future prospect of the project is to work with different kinds of biomass like eucalyptus seed, rice husk etc. and thus achieve maximum reduction in consumption of diesel fuel with increase in efficiency. Also, the properties of the producer gas coming out could be studied and it could be compressed to achieve better results.

Further, the emission characteristics can be analyzed for each kind of biomass and thus the suitable biomass can be selected that optimizes both consumption of diesel fuel and produces least emissions.

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